Diffusion of spins in a strongly spatially varying local magnetic field

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Motivation

– An understanding of spin behavior in semiconductors would enhance the field of spin based electronics (spintronics).

– Spintronics can achieve logical operations with several advantages over conventional methods, including:

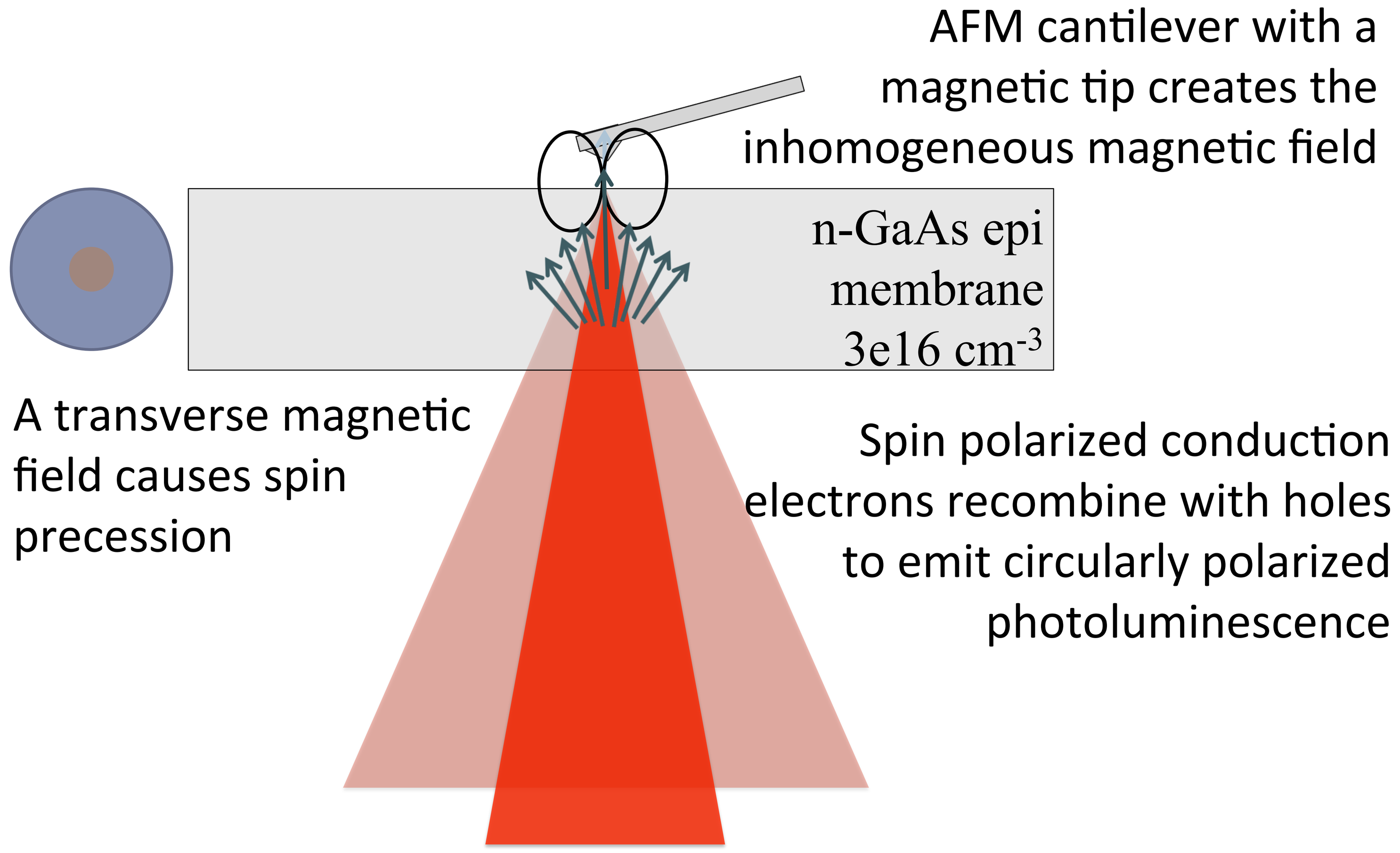
- Lower power consumption
- Non-volatility
- Faster data processing

– The purpose of this research is to understand spin behavior in the presence of magnetic field gradients.

– **These spatially varying fields can enable the encoding of spatial spin properties into the spin polarization data. This allows for the investigation of spin properties at the local level.**

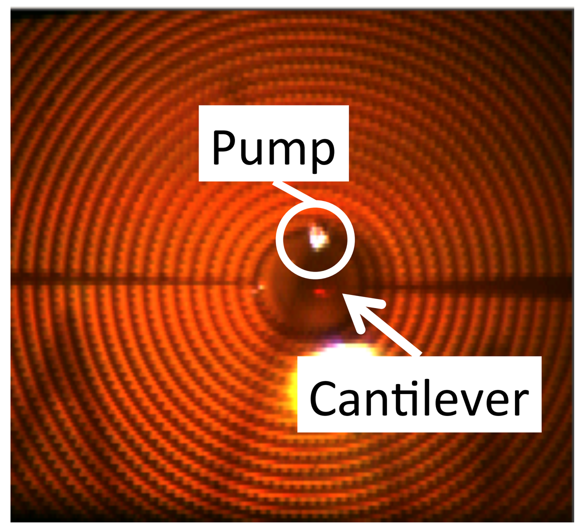
– This work focuses on simulating the experiment being done in the laboratory to study the behavior of spins in field gradients.

Experimental Setup



Circularly polarized light [pump beam] injects spins into the conduction band of GaAs

Optical micrograph of the sample and cantilever, with the pump spot aligned over the micromagnetic particle



The Spin Diffusion Equation

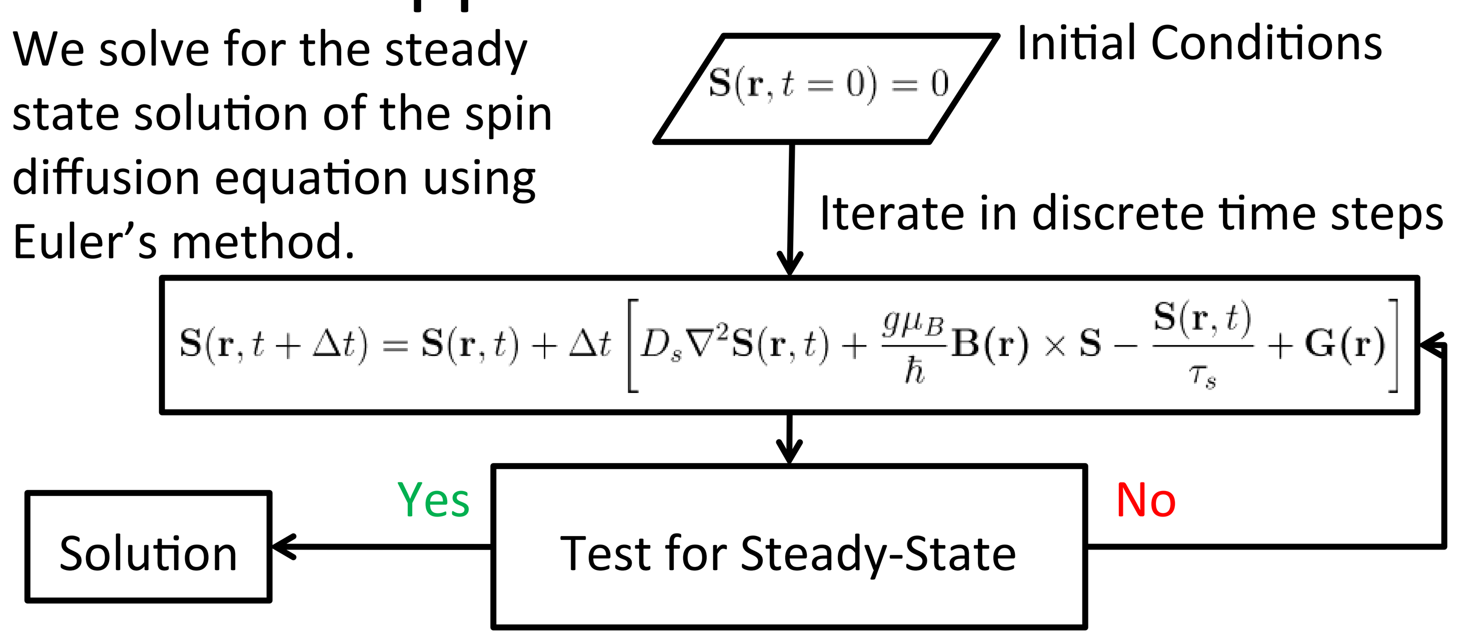
– For this experiment, spin behavior can be modeled by the spin diffusion equation, ignoring spin-orbit and hyperfine interaction.

$$\frac{\partial \mathbf{S}}{\partial t} = \underbrace{D_s \nabla^2 \mathbf{S}}_{\text{Diffusion due to density gradient}} + \underbrace{\frac{g\mu_B}{\hbar}\mathbf{B}\times\mathbf{S}}_{\text{Precession due to transverse field}} - \underbrace{\frac{\mathbf{S}}{\tau_s}}_{\text{Relaxation}} + \underbrace{\mathbf{G}}_{\text{Generation by laser light}}$$

S:	Spin density/polarization	L_s:	Spin diffusion length = $\sqrt{D_s \tau_s}$
D_s:	Spin diffusion constant	B:	Transverse magnetic field
τ_s:	Spin lifetime	G:	Generation rate of spins

Numerical Approach:

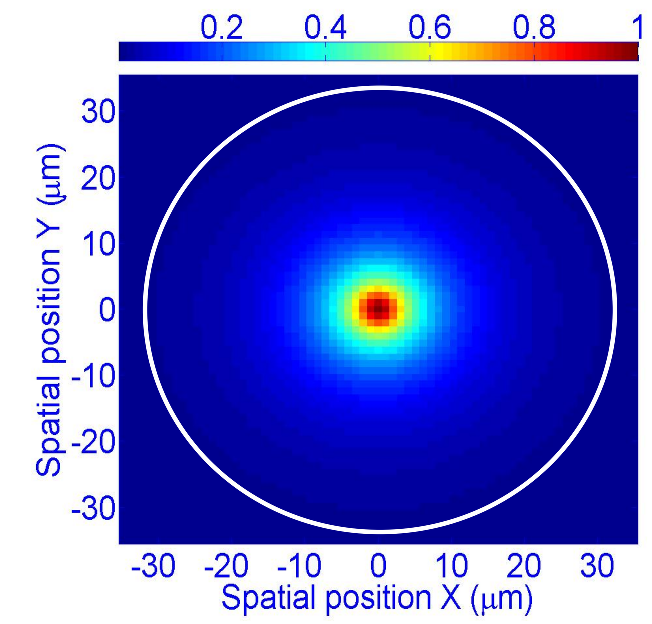
We solve for the steady state solution of the spin diffusion equation using Euler's method.

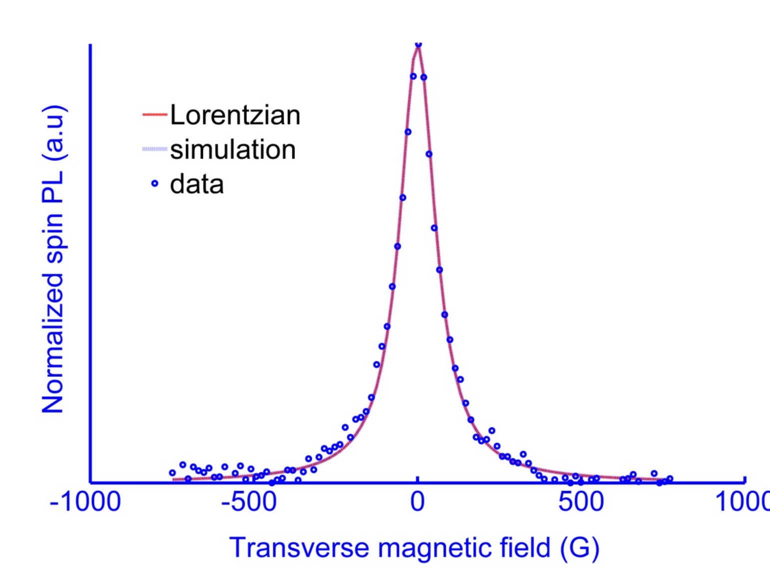


Uniform Transverse Magnetic Field

– This method was first used to verify the uniform transverse magnetic field case ignoring diffusion, for which an analytical solution exists.

– Diffusion effects can be disregarded in this case due to the spin polarization being averaged over an area much larger than the spin diffusion length and pump size.





–The simulations agree well with the experimental results and analytical solution.

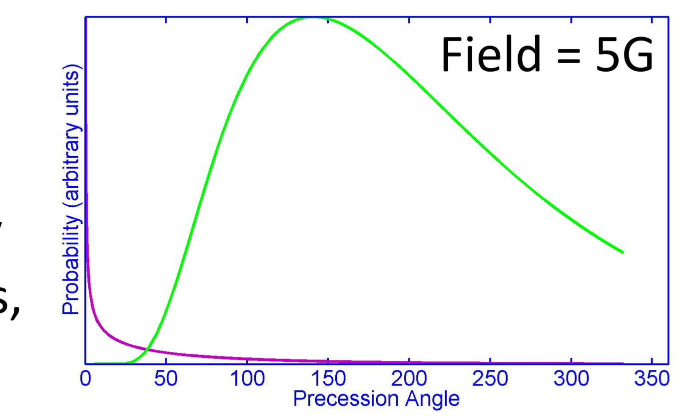
$$S_z(B_y) = \frac{S_0}{1 + \left(\frac{g\mu_B}{\hbar} B_y \tau_s\right)^2}$$

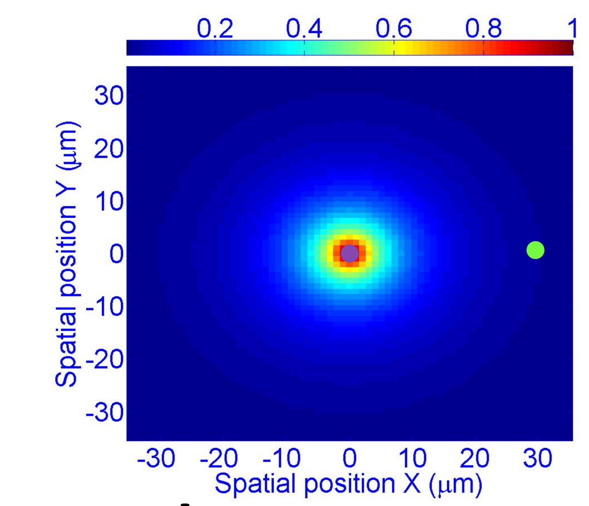
Locally Probing Diffusion Effects

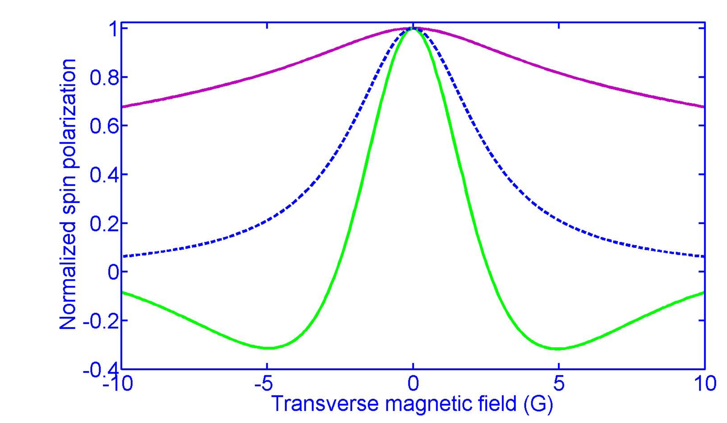
– When the probe size is reduced , the transverse magnetic field dependence changes based on the local spin population coherence.

–The width of this probability curve determines the coherence of the probed spins.

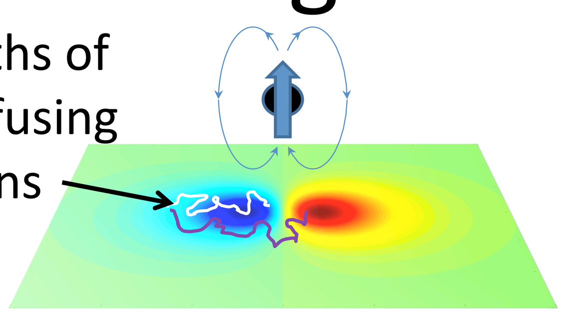
– As the probe moves away from the injection spot, the probability of the spin precession angle shifts, as only the longer lived spins survive.





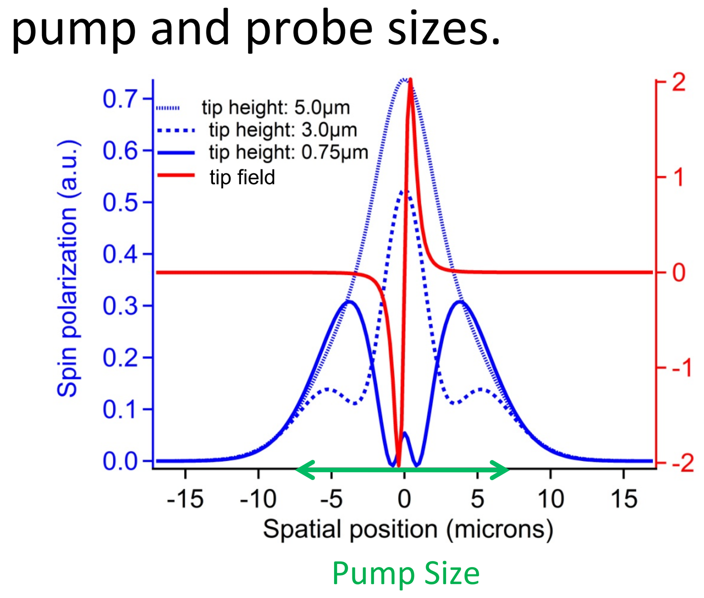


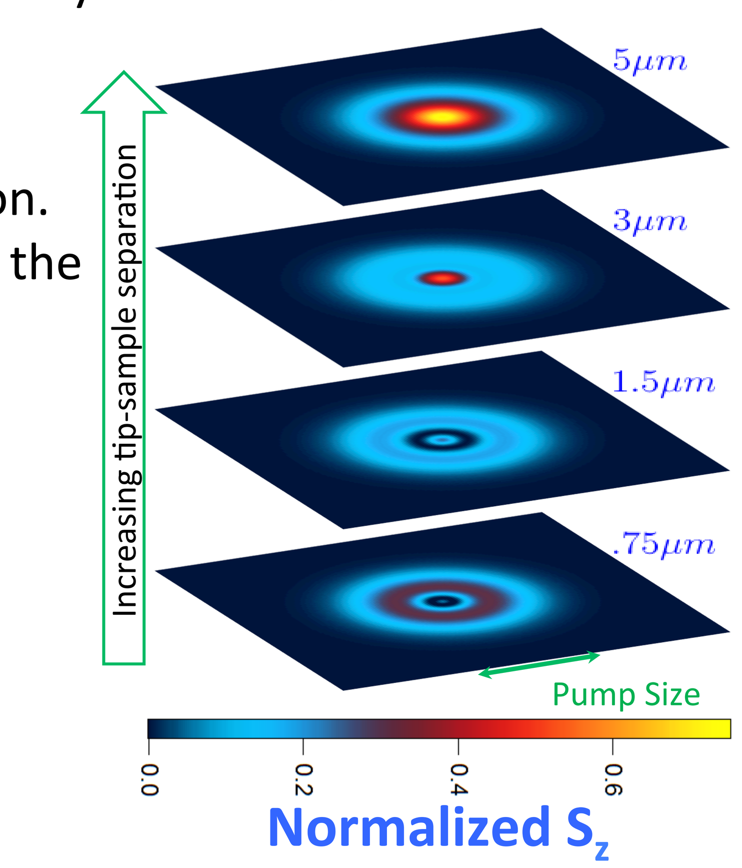
Inhomogeneous Magnetic Field



– Spins precess around the local magnetic field vector, leading to a complex situation for which no analytical solution exists.

– The transverse component of the dipole field determines the spatial features seen in the spin distribution. These features can be smaller than the pump and probe sizes.





Conclusions

– Features smaller than the pump size can be observed in an inhomogeneous magnetic field, allowing for the encoding of local spin information.

– The results from these simulations will be verified by comparing them to experimental data.

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